Evidence for Large Prehistoric Earthquakes in the Northern New Madrid Seismic Zone, Central United States

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ABSTRACT

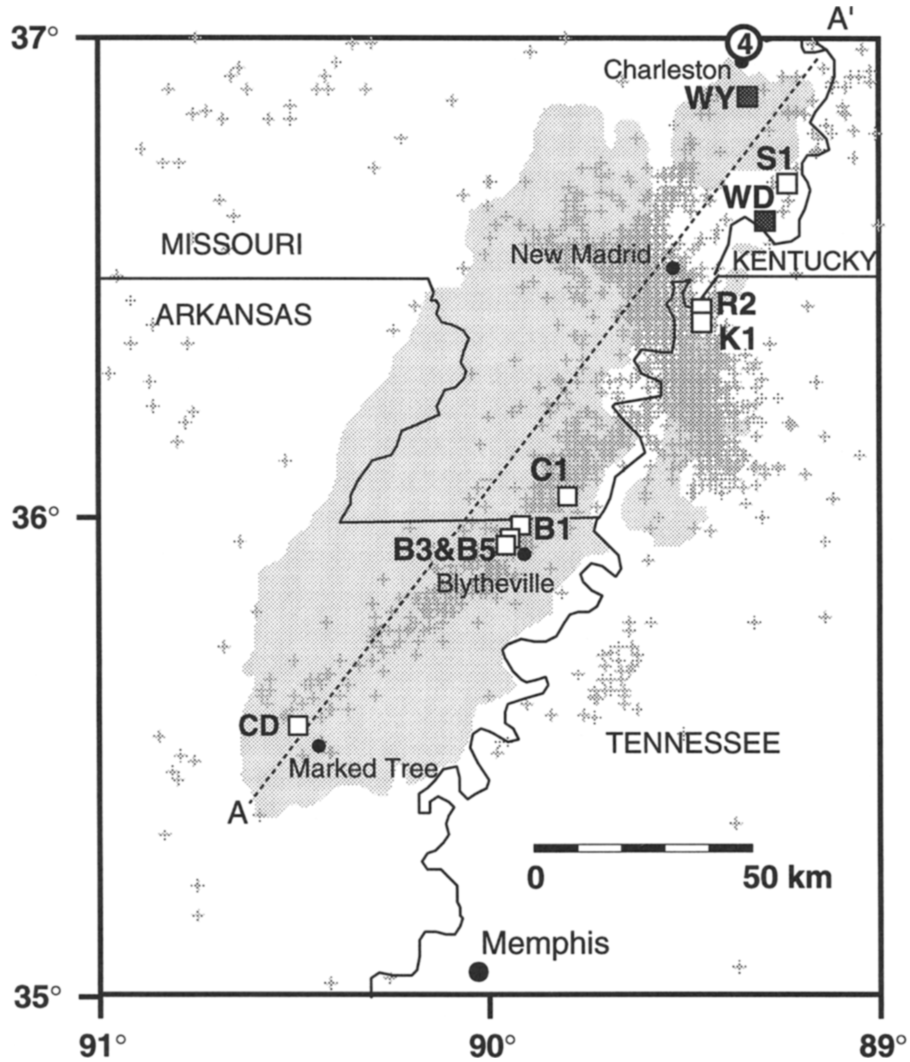
We surveyed the area north of New Madrid, Missouri, for prehistoric liquefaction deposits and uncovered two new sites with evidence of pre-1811 earthquakes. At one site, located about 20 km northeast of New Madrid, Missouri, radiocarbon dating indicates that an upper sand blow was probably deposited after A.D. 1510 and a lower sand blow was deposited prior to A.D. 1040. A sand blow at another site about 45 km northeast of New Madrid, Missouri, is dated as likely being deposited between A.D. 55 and A.D. 1620 and represents the northernmost recognized expression of prehistoric liquefaction likely related to the New Madrid seismic zone. This study, taken together with other data, supports the occurrence of at least two earthquakes strong enough to induce liquefaction or faulting before A.D. 1811 and after A.D. 400. One earthquake probably occurred around A.D. 900 and a second earthquake occurred around A.D. 1350. The data are not yet sufficient to estimate the magnitudes of the causative earthquakes for these liquefaction deposits although we conclude that all of the earthquakes are at least moment magnitude $\mathbf{M} \sim 6.8$, the size of the 1895 Charleston, Missouri, earthquake. A more rigorous estimate of the number and sizes of prehistoric earthquakes in the New Madrid seismic zone awaits evaluation of additional sites.

INTRODUCTION

The New Madrid seismic zone (NMSZ) spans northeastern Arkansas, southeastern Missouri, and western Tennessee and is the most seismically active area in the Central and Eastern United States (Figure 1). Three strong earthquakes of moment magnitude $\mathbf{M} \geq 7.8$ occurred in the NMSZ during a three-month period in the winter of 1811 and 1812 (Johnston, 1996). Sand blows and other liquefaction features caused by these earthquakes cover a broad area of over 10,500 km^2 (Saucier, 1991). If an earthquake similar to the 1811–1812 events were to occur today, it would cause tremendous damage to the region. A major task for earthquake hazards reduction in the New Madrid seismic zone is to accurately determine how often large earthquakes occur in the region. Paleoearthquake studies currently provide the most direct method of determining the timing and magnitudes of prehistoric earthquakes.

Recently, many sites containing evidence of pre-1811 earthquakes have been found in the central and southern New Madrid seismic zone (*e.g.*, Kelson, *et al.*, 1992, 1996; Tuttle and Schweig, 1995; Tuttle *et al.*, 1996b, c). This study was focused in the northernmost New Madrid seismic zone, in the area close to the northern margin of intense liquefaction induced by 1811–1812 earthquakes as mapped by Obermeier (1989).

We surveyed the area north of New Madrid, Missouri, in an effort to determine if pre-1811 liquefaction deposits are present. This work was initiated following the findings of Saucier (1991), who had reported two episodes of pre-1811 earthquake liquefaction at the Towosahgy archaeological site in southeastern Missouri (S1 in Figure 1). It was hoped that the total area affected by the Towosahgy events could be determined and earthquake magnitudes estimated. In the intervening time, however, pre-1811 liquefaction has been demonstrated throughout the seismic zone. Thus, this



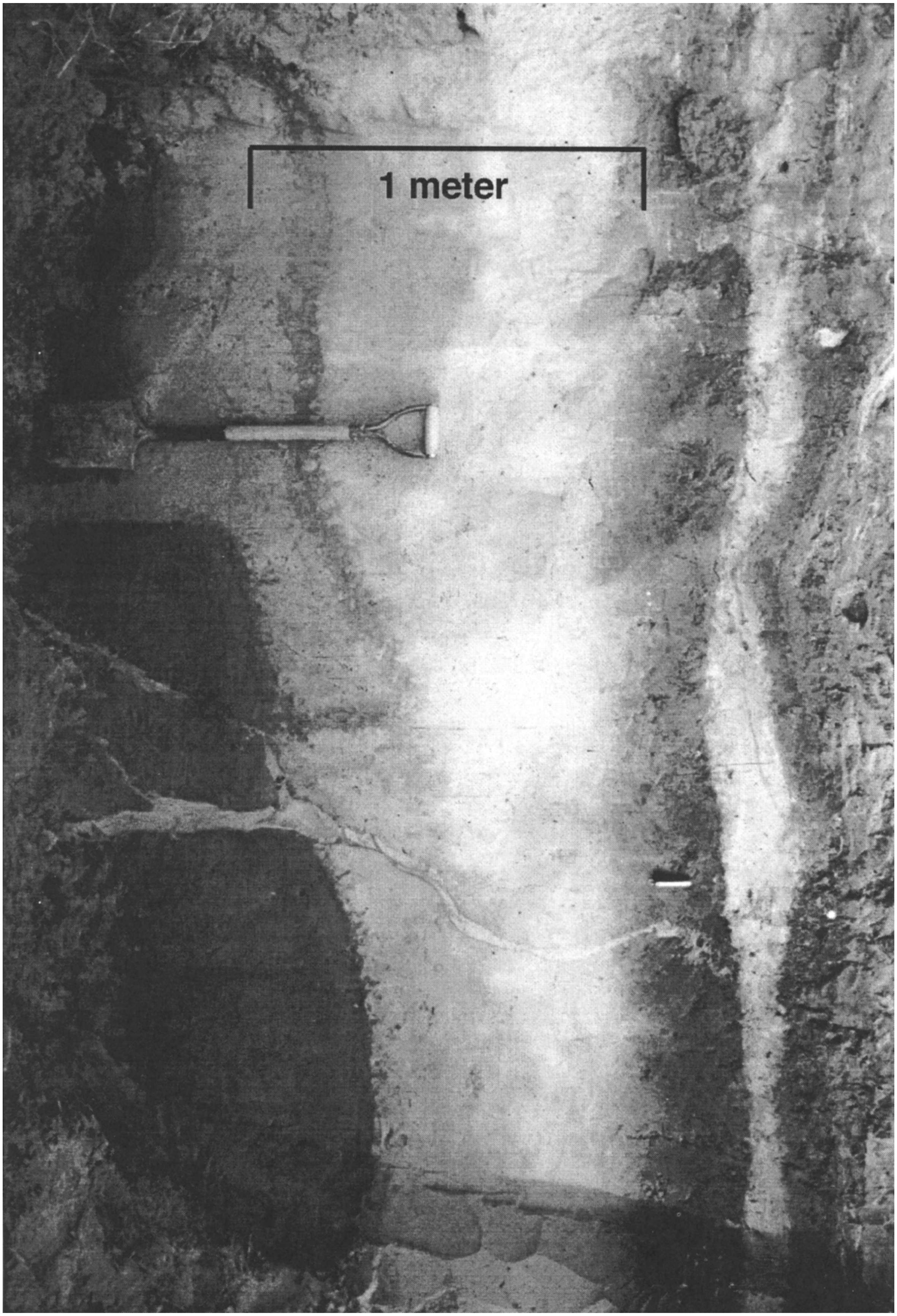
▲ **Figure 1.** New Madrid seismic zone and paleoearthquake sites. Black squares, (WD, WY) locations described in this study; white squares, other studies referred to in text. WD, WY=this study, C1=Craven (1995), S1=Saucier (1991), R2=Russ *et al.* (1978); K1=Kelson *et al.* (1992; 1996). Other sites (B3, B5, B1, CD) Tuttle and Schweig (1995), Tuttle *et al.* (1996b, c). Crosses indicate instrumentally determined seismicity (1974–1991). Shading represents > 1% of ground surface covered by sand-blow deposits (Obermeier, 1989). Dashed line is projection line for Figure 5.

project has become one piece of a larger project to determine the rate of occurrence of damaging earthquakes in the New Madrid seismic zone. This paper presents the northernmost unequivocal evidence of prehistoric paleoliquefaction found in the New Madrid seismic zone to date and, in conjunction with other published data, discusses possible minimum magnitudes for the causative earthquakes.

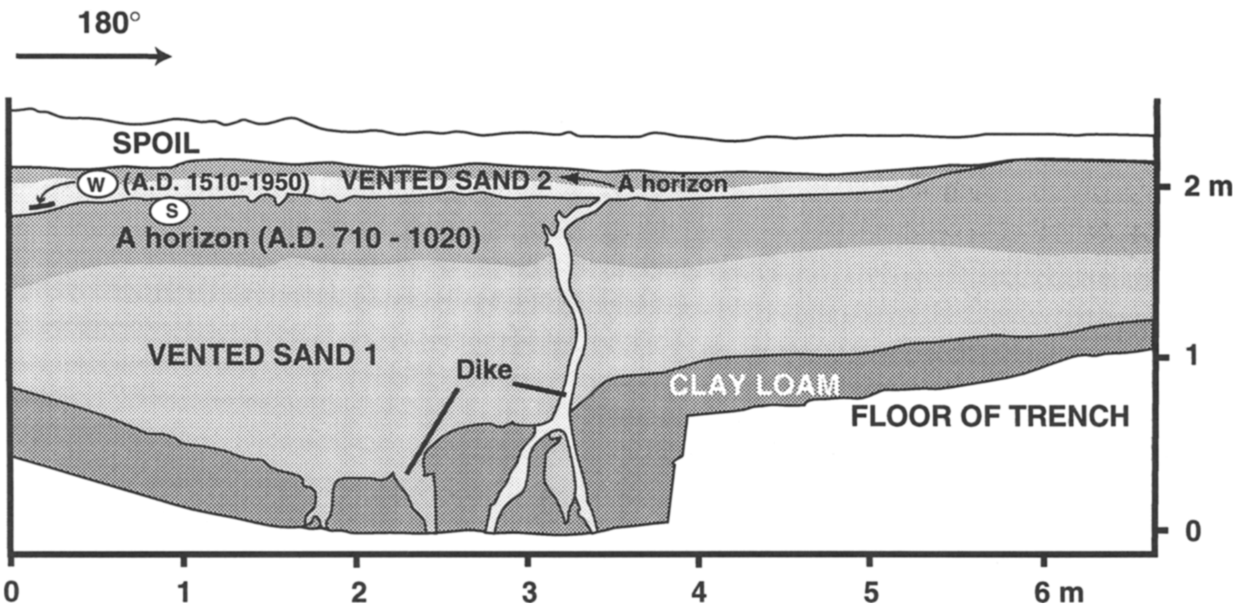
PREVIOUS STUDIES

Prior to this study, the northernmost evidence for pre-1811 earthquake liquefaction attributed to New Madrid seismicity was documented and dated at the Towosahgy site (location S1 on Figure 1). Saucier (1991) reported evidence of two prehistoric earthquakes in the form of liquefaction deposits at the site. One earthquake was estimated to have occurred between A.D. 539 and A.D. 991. A second event was determined to have occurred earlier than A.D. 539, but probably not much earlier. Obermeier *et al.* (1991) have described dikes in southern Illinois that may have been generated in the 1811–1812 earthquake sequence. Tuttle *et al.* (1996a) have documented prehistoric liquefaction features also in southern Illinois and have determined that they are late Holocene in age, but have not attributed them to a particular seismic source.

South of Towosahgy, especially in the central New Madrid seismic zone, many sites with evidence of pre-1811 earthquakes have been reported. Russ *et al.* (1978) and Russ (1979) uncovered evidence for two pre-1811 earthquakes strong enough to induce surface faulting and liquefaction within the past 2,000 years at the Reelfoot scarp (R2 on Figure 1), a feature in part generated by the 1811–1812 earthquakes. More recently, Kelson *et al.* (1996; 1992) found evidence at



▲ **Figure 2.** Photo of Wilkerson Ditch trench, looking east. Note feeder dike on right hand side connects with upper sand blow.



▲ **Figure 3.** Simplified log of Wilkerson Ditch site. W indicates sampling position for radiocarbon date on wood, S for radiocarbon date on dispersed carbon in soil. Black dot and lines indicate positions of tree roots.

the Reelfoot scarp for a paleoearthquake between A.D. 1310 and A.D. 1540 and evidence for another event prior to A.D. 900 (K1 in Figure 1). Farther south near Blytheville and Marked Tree, Arkansas, sand blows and dikes at several sites (B1, B3, B5, and CD in Figure 1) indicate that at least two strong earthquakes occurred prior to A.D. 1670 and within the past 2,000 years, probably around A.D. 900 and A.D. 1300 (Tuttle and Schweig, 1995; Tuttle *et al.*, 1996b, c)

NEW PRE-1811 EARTHQUAKE EVIDENCE

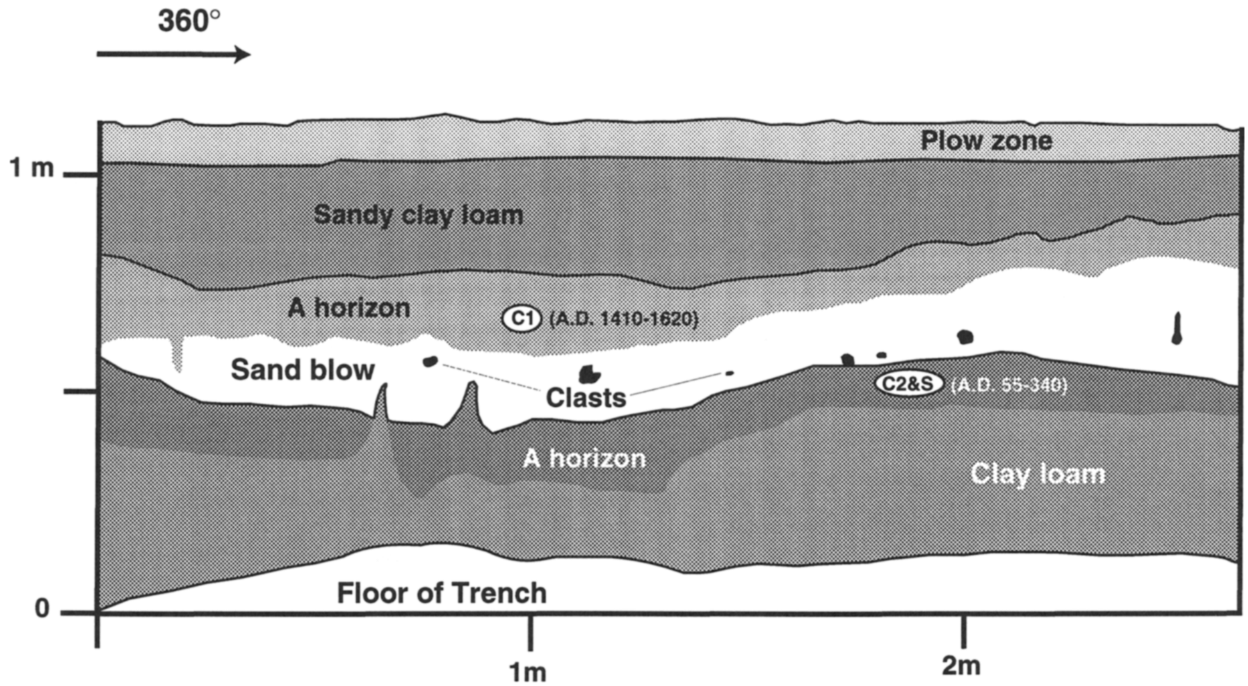
This study uncovered two sites containing evidence of pre-1811 earthquakes in the northern New Madrid seismic zone. The Wilkerson Ditch site (WD on Figure 1) is located ~20 km northeast of New Madrid, Missouri, and ~8 km west of Towosahgy, near the margin of a cluster of sand blows. We exposed two sand blows and their corresponding feeder dikes in a cut bank at this site (Figures 2 and 3). An A horizon as thick as 37 cm is developed in the lower sand blow and a 10-cm thick A horizon is developed in the upper sand blow. Both the lower sand blow and its A horizon are crosscut by the feeder dike of the overlying sand blow. The lower sand blow has a minimum exposed diameter of 10 m. The upper sand blow has a diameter greater than 5 m and is much thinner than the lower sand blow. The younger dike strikes about N40°W, similar to the orientation of other sand blows found on the surrounding surface. The strike of the older dike appears to have a similar trend to the younger dike.

We collected a small twig buried by the upper sand blow (sample W on Figure 3) for radiocarbon analysis. The analysis yielded a radiocarbon age of 240 ± 60 B.P. (Beta-71233), which corresponds to 2σ calibrated calendar age ranges of A.D. 1510 to A.D. 1950[1]. Its stratigraphic position relative to the twig indicates that the upper sand blow was probably deposited after A.D. 1510, possibly during the 1811–1812 earthquakes or another unidentified post-A.D. 1510 event. Carbon-14 analysis on dispersed carbon from the buried A horizon in the lower sand blow (sample S on Figure 3) yields a radiocarbon age of 1140 ± 60 years B.P. (Beta-71234), which corresponds to 2σ calibrated age range of A.D. 770 to A.D. 1040. Therefore, the lower sand blow was deposited prior to A.D. 1040. Tuttle and Schweig (1996) compared the thickness of the buried A horizon on the lower sand blow (37 cm) to A-horizon development on other dated sand blows and inferred that the lower sand blow was exposed at the surface for about 800±100 years prior to burial by the overlying sand blow. The sand blows and their associated dikes, as well as their cross-cutting relationships exposed at this site, provide strong evidence of at least one large pre-1811 earthquake in the northern New Madrid seismic zone.

The Wyatt site (WY in Figure 1) is located in the middle of a sand blow cluster about 45 km northeast of New Madrid, Missouri. In the excavation for this study, a 30-cm-thick, lens-shaped and highly weathered sand blow is overlain by an average of 30 cm of clay loam related to slackwater deposition postdating the earthquake (Figure 4). This buried sand blow contains abundant clay clasts apparently carried up from below when sand-bearing water vented to the surface and is characterized by a ~20 cm thick A horizon. The diameter of the sand blow is at least 6 m.

Carbon-14 analysis on charcoal from the A horizon developed in this sand blow (C1 on Figure 4) yielded a radiocarbon age of 480 ± 60 year B.P. (Beta-74810), which corre-

1. Calibrated ages are in calendar years and are determined by the Pretoria procedure of Vogel *et al.* (1993).



▲ **Figure 4.** Simplified log of Wyatt site. C1, C2, and S indicate sampling positions for radiocarbon dates.

sponds to 2σ calibrated age range of A.D. 1400 to A.D. 1620. Therefore, the liquefaction at this site was deposited earlier than A.D. 1620.

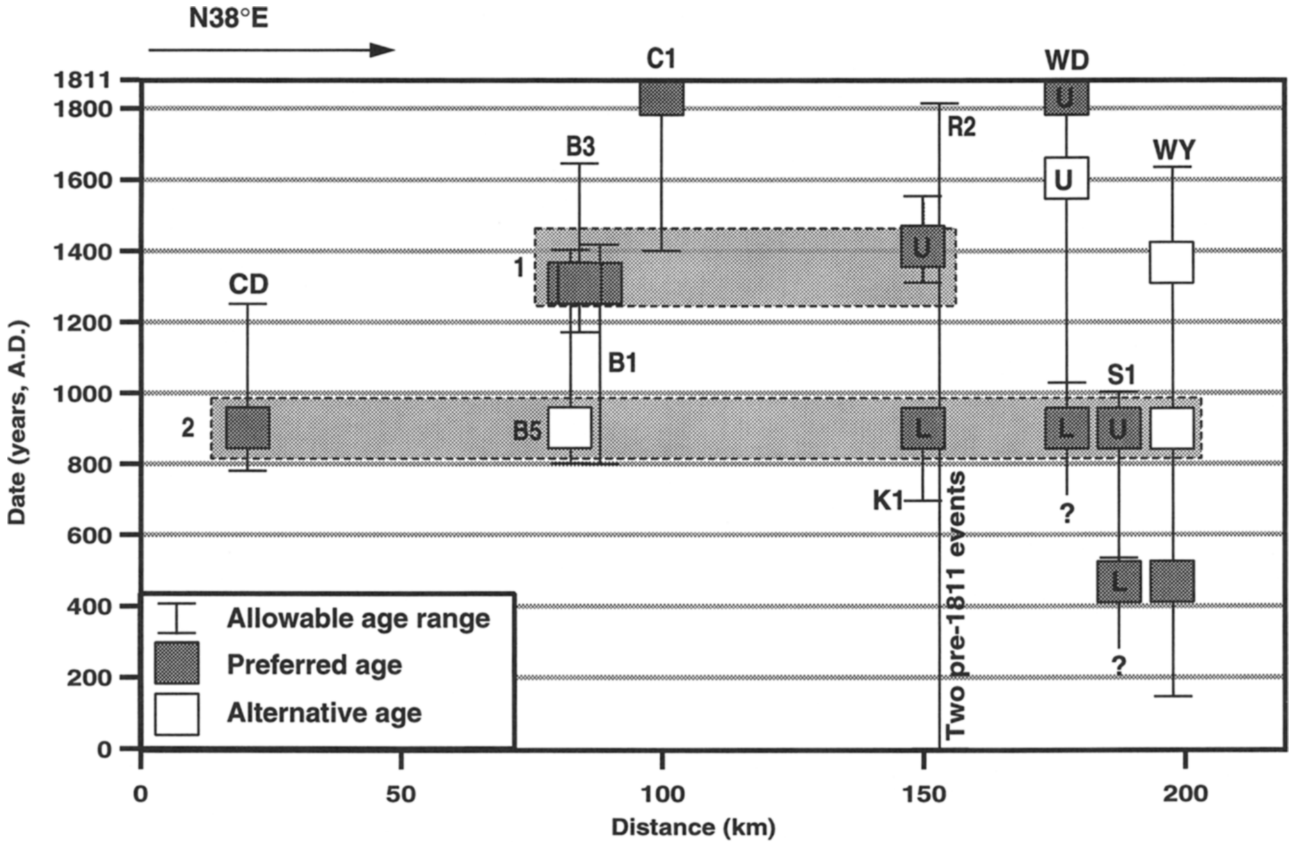
Two samples were collected from the A-horizon buried by the sand blow, one of dispersed carbon (S on Figure 4) and one of charcoal (C2 on Figure 4). S yielded a radiocarbon age of 2060 ± 60 year B.P. (Beta-92884), which corresponds to 2σ calibrated age range of 195 B.C. to A.D. 75. C2 yielded a similar radiocarbon age of 1850 ± 60 year B.P. (Beta-92883), corresponding to 2σ calibrated age range of A.D. 55 to A.D. 340. Thus, the sand blow was likely deposited between A.D. 55 and A.D. 1620, using the broad 2σ ranges and favoring the charcoal date of C2 over the date on dispersed carbon. The Wyatt site represents the northernmost recognized expression of prehistoric liquefaction likely related to the New Madrid seismic zone (Figure 1) and shows that the northern extent of pre-1811 liquefaction is at least equivalent to Obermeier's (1989) mapped northern limit of dense sand blow distribution.

REGIONAL IMPLICATIONS

The results of this study strongly support Saucier's (1991) finding that earthquake-induced liquefaction occurred at least once prior to 1811–1812 in the northern New Madrid region. In order to better understand the context of these northern sites, they must be evaluated in terms of their spatial and temporal relationship to other paleoseismological sites in the New Madrid seismic zone. Figure 5 summarizes the distribution of ages of prehistoric earthquakes from this and other recently published studies. The data taken together support the occurrence of at least two earthquakes strong enough to induce liquefaction or faulting before A.D. 1811 and after A.D. 400. One earthquake probably occurred around A.D. 900, which may have caused the lower sand blow at the Wilkerson Ditch site (WD in Figures 1 and 5), as well as one of the liquefaction events at Towosahgy (Saucier, 1991; S1 in Figures 1 and 5). A second earthquake occurred around A.D. 1350. The age is constrained best by dated deformation exposed at the Reelfoot scarp (Kelson *et al.*, 1996; K1 in Figures 1 and 5). Thus, earthquakes strong enough to have generated widespread liquefaction occurred in A.D. 1811–1812, and probably within a hundred years of A.D. 1350 and A.D. 900.

The age of liquefaction at the Wyatt site (WY on Figures 1 and 5) is not well constrained. If it was generated by the A.D. 900 earthquake, estimates of the minimum area affected by this earthquake, and therefore estimates of the minimum size of the causative earthquake, increases significantly. In this scenario, one large earthquake occurred around A.D. 900 with liquefaction deposits spanning a minimum of 196 km from Marked Tree, Arkansas, to Wyatt, Missouri (horizontal rectangle labeled 2 in Figure 5). The A.D. 1350 earthquake perhaps had a more limited liquefaction area (spanning a length of at least 75 km) south of the Reelfoot scarp (horizontal rectangle labeled 1 in Figure 5).

A second possible scenario assigns the Wyatt site to the younger earthquake (A.D. 1350). In this case, liquefaction caused by the A.D. 900 event spans an area from Marked Tree to the Wilkerson Ditch and Towosahgy sites to the



▲ **Figure 5.** Correlation of liquefaction events for the New Madrid seismic zone. All dated liquefaction sites shown on Figure 1 are projected onto profile A-A'. Letters L and U in squares refer to lower and upper sand blows, respectively, at some sites. In our preferred scenario, liquefaction dating from about A.D. 1300 extends at least from site B5 to site K1, a distance of about 70 km (rectangle labeled "1"). Liquefaction from A.D. 900 would then span at least 170 km (rectangle labeled "2"), approaching the length of the zone of intense liquefaction dating from the 1811–1812 earthquakes. Under this scenario, the lower sand blow at site S1 and the sand blow at site WY may reflect a smaller, more local source. Other scenarios are clearly possible.

north, a minimum length of ~175 km. The A.D. 1350 earthquake liquefaction extends a minimum of ~130 km, from Blytheville, Arkansas, to Wyatt, Missouri.

Yet a third scenario is that liquefaction at the Wyatt site does not correlate with the sites south of Towosahgy, but rather represents a local earthquake or a separate source to the north. In this case, a possibility is that the liquefaction at the Wyatt site was caused by the same event that produced the ~A.D. 500 liquefaction at Towosahgy (Saucier, 1991), about 22 km to the south-southeast.

How can one estimate the magnitudes of the causative earthquakes? One approach is to use published empirical relations between moment-magnitude and the maximum distance of liquefaction from an epicenter. Worldwide data suggest that this is a linear relationship (Youd *et al.*, 1989). However, the variability within the worldwide database is quite large and the lower attenuation values in eastern North America suggest that an equivalent magnitude earthquake will cause a greater areal distribution of liquefaction in the New Madrid seismic zone than, for example, in California.

A better approach would entail deriving a local relationship between magnitude and epicentral distance from earthquake data in the New Madrid region. Such a local relationship would be more suitable for this study because of the more constant geological conditions (*e.g.*, soil profile, ground water table, etc.) and attenuation. Unfortunately, the paucity of local historic liquefaction data does not permit us to establish such a quantitative relationship between local magnitude and epicentral distance. In fact, this study and others referenced earlier show that it is not safe to assume that the mapped area of liquefaction shown by Obermeier (1989) is related solely to the 1811–1812 earthquake sequence, in spite of its clear spatial relationship with New Madrid seismicity, because we do not know the ages of the mapped liquefaction deposits. It may be possible to conclude that all of the earthquakes are at least moment magnitude **M** ~ 6.8, the size of the 1895 Charleston, Missouri, earthquake (Hamilton and Johnston, 1990), and the smallest earthquake known to have caused liquefaction over a broad area (16 km across; Obermeier, 1988). It is likely that the A.D. 900 and A.D. 1300 earthquakes were very large; evidence for these events have been found over a broad area and the sand blows found at the Wilkerson Ditch and many of the sites of Tuttle and Schweig (1995, 1996) are equal to or larger than sand blows presumably related to the 1811–1812 earthquakes found nearby. In summary, the data from the two sites described in this paper suggest two pre-1811 earthquakes that may correlate with two of the earthquakes inferred in regional studies to have occurred about A.D. 500, A.D. 900, and A.D. 1300. The broad distribution as well the sizes of the liquefaction features from the two later earthquakes suggest their magnitudes may be similar to the 1811–1812 earthquakes, *i.e.*, $\mathbf{M} \geq 7.8$. A more rigorous estimate of the number and sizes of prehistoric earthquakes in the New Madrid seismic zone awaits further study of sites. It is clear that much more data will need to be collected from many sites before we are able to confidently correlate sand blows with one another. Furthermore, estimates of magnitudes of prehistoric earthquakes will remain speculative until better methodologies can be developed to determine regional relationships between areal extent of liquefaction and magnitudes of causative events.

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